R 3300-1 U (A) 3/86

Battelle
Columbus Division

Probable Levels of R&D Expenditures in 1986

Forecast and Analysis

This Battelle report is based upon a continuing study of U.S. expenditures for research and development. It was prepared by Drs. Jules J. Duga and W. Halder Fisher of Battelle's Columbus Division. Parts of the data presented here were derived from such sources as the National Science Foundation, the McGraw-Hill surveys, and others.

December, 1985

PROBABLE LEVELS OF R&D EXPENDITURES IN 1986

SUMMARY OF FINDINGS

1. Battelle forecasts that the total U.S. expenditures for R&D will be $116.8 billion during calendar year 1986. This is an increase of 9.5 percent over the $106.6 billion that the National Science Foundation (NSF) estimates actually will be spent in 1985.

2. Costs of performing R&D are expected to rise almost 4.9 percent from 1985 to a 1986 index level of 263.16 (1972 = 100 percent), absorbing a considerable amount of the increased funding. However, this implies a *real* increase in expenditures of approximately 4.4 percent, reaching a new peak in total real funding of R&D (Figure 3).

3. Federal government funding in 1986 is expected to be about $54.5 billion (46.7 percent of total), an increase of $4.8 billion (9.6 percent) from 1985. Performance of R&D by the Federal government will represent $14.0 billion (12.0 percent), an increase of $720 million (5.4 percent) over 1985 estimates.

4. Industrial funding in 1986 is expected to be approximately $58.2 billion (49.8 percent of total) representing an increase of $4.97 billion (9.3 percent) over that of 1985. Performance of R&D by industry is expected to rise to over $85.2 billion (73.0 percent of total), an increase of $7.8 billion (10 percent) over 1985.

5. Estimates of Federal versus industry support for the R&D performed by each of several broad industrial sectors are included in the 1986 forecast. Drawing upon historic trends, the anticipated total performance by the industrial sector has been distributed; first, within each of 17 major industrial groups, and then according to whether that performance is supported by Federal or industrial funds. These estimates are shown in Table 4.

6. In 1986, the Federal government is expected to support more than three-fourths of the aerospace industry's R&D activity, almost two-fifths of electrical machinery/communications, and about one-fifth of the R&D in rubber industries. All other broad manufacturing industry classes are expected to be supported primarily by industry funds. These ratios range from 81 percent for ferrous metals up to 100 percent for the textile, paper, and the food and beverage industries. Overall, 32.8 percent of industrial R&D will be Federally funded with the remainder (67.2 percent) funded by industry.

7. Academic and other nonprofit institutions taken together are expected to fund $4.04 billion of R&D in 1986 (3.46 percent of total) and to perform almost $17.5 billion (15 percent). Both of these figures represent significant increases in the percentage of support and performance over the 1985 NSF estimates. These figures also include the Federal support to Federally Funded Research and Development Centers which are managed by individual universities or consortia.

8. Within the nonprofit category, colleges and universities are expected to account for 63.6 percent of the 1986 funding and 80.2 percent of the R&D performance, an insignificant difference from the 1985 NSF estimates.

9. The costs of R&D performance have risen steadily in all four categories (Federal, industrial, colleges and universities, and other nonprofits), with the rate of increase being driven partially by overall inflation, but primarily by the so-called "sophistication" factor.

10. The trends in real R&D effort (see Figure 3) are continuing the upward movement established over much of the past decade. Since 1975, real R&D effort has increased at a 10-year average rate of 3.83 percent, and the projections for 1986 suggest that the 11-year average rate will be essentially unchanged. Battelle estimates that during the decade of the 1980s, and into the early 1990s, real R&D activity will increase at an average annual rate of approximately 3.5 percent, tapering off slowly from the present growth.

11. Significant factors that appear to be influencing trends in the support and performance of R&D include:

    (a) Federal emphasis on defense and space programs will have a continued influence on total R&D support and the principal industrial performers; these emphases will be felt primarily in the aerospace and electronics and communications industries.

(b) Energy-related R&D programs will continue to experience decreased Federal support, with the exception of programs characterized as having very high risk or long-term payoff; even within these categories, there is little evidence that energy is perceived as a national problem requiring Federal R&D support.

(c) Increased industrial support of R&D may be reflecting the impact of the tax credits instituted four years ago.

(d) University self-funding of R&D is expected to continue to show real increases, partially as a result of expanded industrial "directed programmatic endowment" support of basic and applied research.

(e) The enactment and implementation of the Gramm-Rudman Bill may have a significant impact on the rate of growth of government funded R&D.

12. As a special feature, the report provides a preliminary forecast of R&D funding levels in 1987. The preliminary data show the total U.S. expenditure for R&D in 1987 to be $120.8 billion (uncorrected for inflation).

13. An additional new feature of this report is a preliminary detailed line-of-business R&D estimate which covers 130 productive sectors of the U.S. economy.

ANALYSIS AND FORECAST

Since research and development (R&D)* is one of Battelle's prime concerns, it has an intense and abiding interest both in forecasting R&D expenditures and in assessing the cumulative results of R&D activities—technological, economic, and social. Accordingly, Battelle has carried on a continuing inquiry into the forces affecting R&D activities and into their sources of support. Among the tangible outputs of this research have been a series of annual analyses and forecasts of R&D expenditures, of which the present report is the latest.

*The National Science Foundation's definitions of R&D are given in the Technical Appendix to this report.

The content of this analysis and forecast of the R&D situation has evolved over the years in an attempt to supply information that Battelle considers useful to the R&D community, but was not being supplied by two well-known and respected series of reports: the National Science Foundation's *National Patterns of Science and Technology Resources* and the McGraw-Hill *Annual Survey of Business Plans for R&D.*

Earlier, the NSF *Patterns* were published during the first half of each year (usually in April) and included a forecast of that same full year's R&D expenditures, by source of funds and by performer. However, since the change to the fiscal year which now begins in October, *Patterns* contains both the preliminary data for the closing fiscal year and estimates for the two preceding years. The McGraw-Hill surveys (usually published at about the same time as *Patterns*) make forecasts—the 1985 Survey (published in May) made forecasts for 1985 and 1988—but are confined to the performance of the industrial sector and do not separate Federal from industrial funding. The Battelle report, usually published in December, has been intended to fill in a timely manner the niche that involves especially the coming year (in this case, 1986) and industrially funded R&D. Other relevant information, gleaned from many sources, also has been included.

Beginning with the 1980 forecast, we also have included a forecast of industrial R&D expenditures by broad industry class, along with the estimated distribution of those funds between industrial and Federal sources. This added feature provides the background necessary to an understanding of the way in which Federal policy can affect industrial innovation, can spur industrial support of its own R&D efforts, and can enhance the longer-term international competitiveness of U.S. industry. Although related aspects of productivity, training and manpower needs, tax incentives, balance of payments, and other concerns are not predictable, we anticipate that continued analysis of this subject will help identify both the promises and the problems associated with industrial responses to future opportunities.

Continuing the practice initiated in the 1984 Forecast, estimates are presented which cover a *two*-year forecast, to 1987.

Historical Trends in R&D Funding and Performance

Although the NSF data series goes back to 1953, we begin our analysis with 1960. Even that year repre-

sents ancient history so far as the forces currently affecting R&D are concerned. The NSF data from 1960 through 1985 are shown in Table 1.

In 1960, NSF surveys indicated that approximately 64.6 percent of all R&D supportive funds were provided by the Federal government; 33.4 percent were provided by industry; and 1 percent each came from the academic community and from other nonprofit organizations.

Between then and 1984, Federal funding rose to 66.5 percent in 1964, and has slowly declined to 46.0 percent in 1982 and has slowly risen since that time.** Over that same time period, industrial funding declined to 31.2 percent in 1964 and rose to 50.6 percent in 1982, with a small decline to 49.8 percent expected in 1986. The two nonprofit sectors have risen gradually, colleges and universities to 2.2 percent and other nonprofits to

**Note that NSF data for 1983 and 1984 are "estimated". However, comparisons among the series of *Patterns* reports reveals that adjustments are made on earlier years' figures, with such adjustments carrying back as far as 1977. Thus, many of our calculations that are dependent on long-term figures will vary from one year to the next.

TABLE 1. SOURCES OF R&D FUNDS AND PERFORMERS OF R&D, UNITED STATES, CALENDAR YEARS 1960–1985

(Millions of Current Dollars)

		Sources of Funds				Performance [a]			
Year	Total R&D	Federal Gov't	Industry	Colleges and Universities[b]	Other Nonprofit[c]	Federal Gov't	Industry	Colleges and Universities	Other Nonprofit[c]
1960	13,523	8,738	4,516	149	120	1,726	10,509	1,006	282
1961	14,316	9,250	4,757	165	144	1,874	10,908	1,173	361
1962	15,394	9,911	5,123	185	175	2,098	11,464	1,374	458
1963	17,059	11,204	5,456	207	192	2,279	12,630	1,611	539
1964	18,854	12,537	5,887	235	195	2,838	13,512	1,904	600
1965	20,044	13,012	6,548	267	217	3,093	14,185	2,103	663
1966	21,846	13,968	7,328	304	246	3,220	15,548	2,345	733
1967	23,146	14,395	8,142	345	264	3,396	16,385	2,594	771
1968	24,605	14,928	9,005	390	282	3,494	17,429	2,868	814
1969	25,631	14,895	10,010	420	306	3,503	18,308	2,950	870
1970	26,134	14,892	10,444	461	337	4,079	18,067	3,072	916
1971	26,676	14,964	10,822	529	361	4,228	18,320	3,216	912
1972	28,477	15,808	11,710	574	385	4,590	19,552	3,383	952
1973	30,718	16,399	13,293	613	413	4,762	21,249	3,701	1,006
1974	32,864	16,850	14,878	677	459	4,911	22,887	3,888	1,178
1975	35,213	18,109	15,820	749	535	5,354	24,187	4,396	1,276
1976	39,018	19,914	17,694	810	600	5,769	26,997	4,876	1,376
1977	42,782	21,594	19,629	887	672	6,012	29,825	5,450	1,495
1978	48,129	23,876	22,450	1,037	766	6,811	33,304	6,342	1,672
1979	54,933	26,815	26,081	1,200	837	7,417	38,226	7,296	1,994
1980	62,593	29,451	30,911	1,323	908	7,632	44,505	8,306	2,150
1981	71,839	33,402	35,941	1,523	973	8,425	51,810	9,304	2,300
1982	79,301	36,502	40,088	1,683	1,028	9,141	57,995	9,740	2,425
1983[d]	86,554	40,344	43,245	1,830	1,135	10,582	62,815	10,482	2,675
1984[d]	95,925	44,675	47,975	2,080	1,195	12,300	69,250	11,400	2,975
1985[e]	106,600	49,775	53,210	2,300	1,315	13,300	77,500	12,600	3,200

Source: National Science Foundation, *National Patterns of Science and Technology Resources*, 1985 (preliminary data)

(a) The R&D performance of Associated Federally Funded Research & Development Centers (some administered by industry, some by colleges and universities, and some by other nonprofit organizations) has been combined with that of the administering institutions.

(b) As sources of funds, these include state and local government funding.

(c) All other nonprofit institutions.

(d) Preliminary figures provided by NSF.

(e) Preliminary estimates by NSF.

almost 1.6 percent, although the nonprofit support has declined proportionately over the past eight years.

Through 1982, trends showed a continued increase in industry funding as a percent of total funding, with a corresponding decline in Federal sector contributions. Over the past four years, however, the relative contributions by industry and the Federal government have remained essentially constant. This is largely due to both significant increases in defense spending and industrial response to a healthier economy and other initiatives (see the later discussions on the role of industry).

Although the Federal government had been the major *source* of R&D funds from 1953 to 1979, its dominance has been eroded since 1980. Industry is by far the major *performer* of R&D. Federal performance of R&D rose from 12.7 percent in 1960 to 16.1 percent in 1972 and has been fluctuating since that year, albeit with a generally decreasing percentage. Industrial performance reached a high point of 79 percent in 1957, and drifted steadily downward to a low of 68.6 percent in the early 1970's; more recent trends suggest a slow increase in the proportion of industrial performance, rising to over 74 percent. While the academic community's performance varied between 6 and 8 percent prior to 1960, there has been a slow but steady increase in the percentage of R&D performed in this sector, with recent proportions around 12 percent. Over the past few years (since 1980) this sector's share has been declining slightly although there appears to be a more recent trend toward reversing this decline. Such reversal would result from industrial initiatives (see later). For most of the 1960-80 period, other nonprofits, including Battelle, had grown from 2 to about 3.5 percent of the total, again with recent declines in that share.

It should be noted that Federal funding supports research performed by all four sectors. Currently, almost one-fourth goes to support intramural R&D; over half goes to industry; approximately one-fifth goes to colleges and universities; and the rest, slightly more than 4 percent, goes to other nonprofits. Industry absorbs almost all of its own funds, either intramurally or by contract with other industrial performers; its contracts and grants to colleges and universities slightly exceed those to other nonprofit institutions. Other nonprofits finance both themselves and the academic institutions about equally, while colleges and universities absorb all the funds that they originate.

In Table 1 we summarize the latest NSF time series on the sources of R&D funding and on the volumes of R&D performance. During the interval since 1960 total R&D dollars (not adjusted for inflation) have increased almost eight-fold. Federal funding has multiplied by a factor of 5.7 and Federal performance has increased by a factor of 7.7. In terms of constant dollars, total R&D expenditures have increased by 86 percent during 1960-85, and Federal performance has increased by 33 percent (see Table 6). Using the same deflator for Federal funding that we used for total expenditures, real Federal funding increased by about 34 percent.

Also noteworthy is the high ratio of academic performance to academic funding. In the later years of this period, colleges and universities have provided about one-sixth of the total support of their own R&D activity, with the remainder coming primarily from the Federal government. In recent years, this ratio has tended to decrease, not only as a result of some reduction in selected Federal programs but also due to an increase in academic funding. This latter is largely a "bookkeeping" artifact created by the manner in which university funds are ascribed to the universities, rather than to the ultimate original sources. More will be said about this in later sections of the Forecast.

Beginning in 1968, there was a distinct change in the rate of growth in R&D, manifested by a leveling in current-dollar Federal funding. This phase of the recent past seems to have ended with 1971, when current-dollar expenditures resumed an accelerating growth trend more nearly like that before 1968. More recent trends suggest a continued growth of total real R&D support, although the rate of growth may begin to slow.

The continuing transition in the support and performance of R&D, to which we referred in the 1983 and 1984 forecasts and analyses, has had a significant impact on the patterns within the overall R&D enterprise. The Federal government has developed and maintained—albeit over the strong objections of both academia and some industry—a posture that has influenced the type and extent of Federal support. There is perhaps no stronger evidence of this than the major restructuring of Federal programs in energy and social services. In each of these cases, it has not been merely the change in Federal *actions* that have impacted the research community, but it is more the change in *philosophy* which has permeated the scene.

In general, the more conservative philosophy has been willing to stand up to the pressures of single focussed interests and pursue fundamental postures of independence from central government actions. This has

been evidenced in the encouragement of R&D within the private sector, the determination to let the marketplace decide the most fruitful areas for private investment, and the return to the subnational levels of government those functions which are deemed most appropriate for State or local action.

The strongest Federal actions, as we shall see in later sectons of this forecast and analysis, remain in those areas that are of fundamental concern to the central government: (1) national defense; (2) technological competition from our trading partners; (3) health; and (4) the environment for economic growth. The extent to which Federal actions can influence these areas will continue to be dependent upon a number of different factors, including the response to military and/or diplomatic tensions throughout the world, and the pervasive question of the massive national debt.

Forecast for 1986

During calendar year 1986, Battelle expects the total current dollar volume of R&D activity to be higher than the level estimated by NSF to be achieved in 1985. A comparison of Battelle's 1986 forecast with the last available NSF estimates for 1985 is shown in Table 2. The 1986 forecast is shown in its historical setting in Figure 1.

Referring to Table 2, we estimate total 1986 R&D volume to be $116.8 billion, a 9.5 percent increase over the NSF estimates for 1985. It is expected that much of this increase will be absorbed by continued inflation (which we estimate to be 4.9 percent from 1985 to 1986 for R&D).

In connection with this forecast, there are several important factors that must be recognized. First, the total current-dollar projected increase includes an inflation factor that depends significantly on the inflation rate as it specifically applies to R&D. As will be noted in the discussion of the Cost of Research Index, this inflation factor is fundamentally different from that associated with the more familiar consumer price index.

In addition, it is apparent that concerns over the Federal budget will influence the remaining appropria-

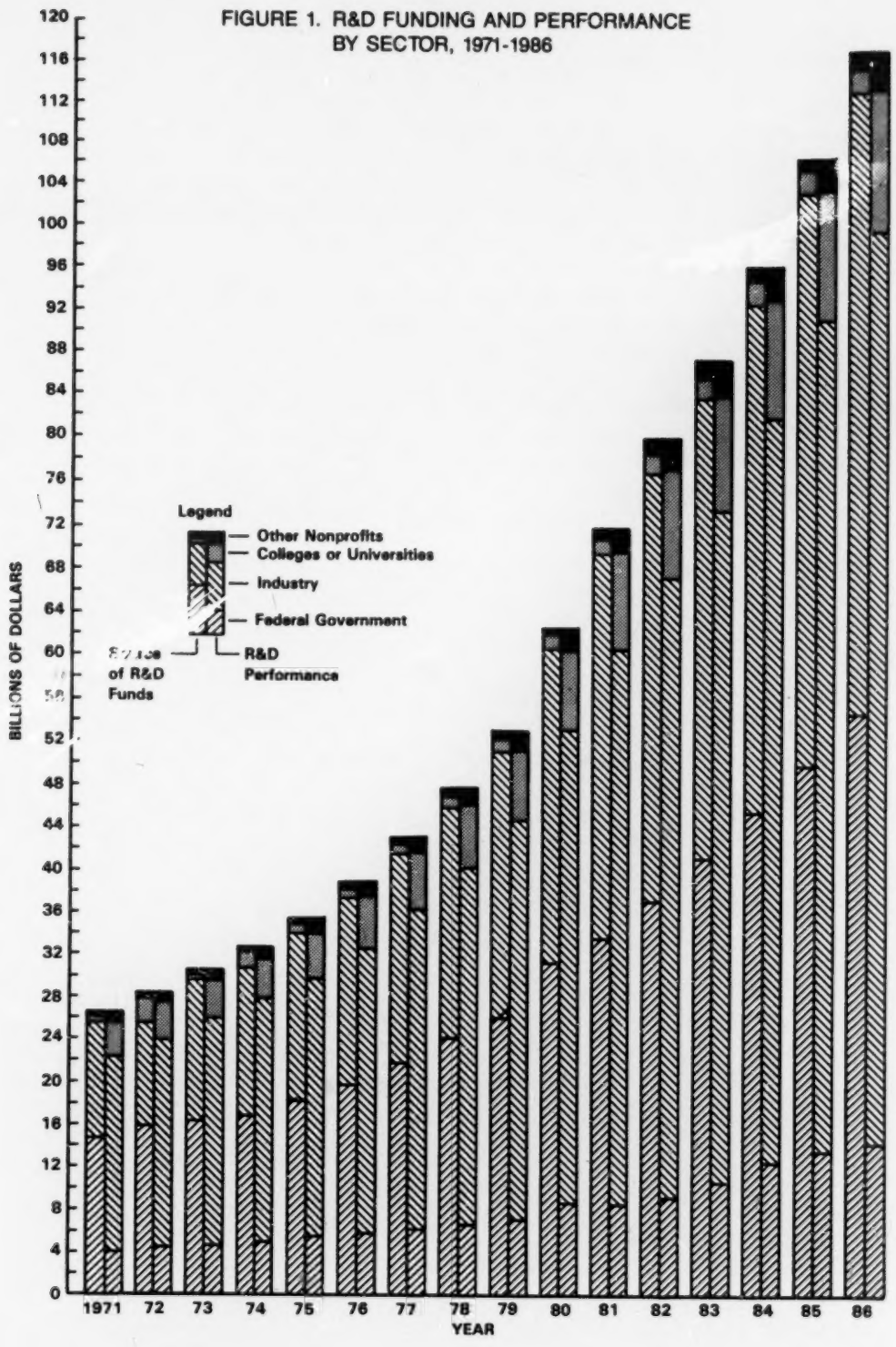
TABLE 2. ESTIMATED R&D EXPENDITURES BY SOURCE OF FUNDS AND BY PERFORMERS, U.S. CALENDAR YEARS 1985 AND 1986

(Millions of Current Dollars)

Source of Funds	Performer: Federal Government	Performer: Industry	Performer: Colleges and Universities	Performer: Other Nonprofit	Source Totals: Dollars	Source Totals: Percent of All Funds
1985 NSF ESTIMATES*						
Federal Government	13,300	25,100	9,125	2,250	49,775	46.69
Industry	—	52,400	485	325	53,210	49.91
Colleges & Universities	—	—	2,300	—	2,300	2.15
Other Nonprofit	—	—	690	625	1,315	1.23
Performer Dollars	13,300	77,500	12,600	3,200	106,600	100
Totals Percent	12.47	72.70	11.81	3.00		
1986 BATTELLE FORECAST						
Federal Government	14,022	27,977	10,111	2,431	54,541	46.71
Industry	—	57,288	551	340	58,180	49.82
Colleges & Universities	—	—	2,570	—	2,570	2.20
Other Nonprofit	—	—	785	686	1,471	1.25
Performer Dollars	14,022	85,265	14,016	3,457	116,761	
Totals Percent	12.01	73.03	12.00	2.96		100
PERCENTAGE INCREASES OVER 1985 ESTIMATES						
Federal Government	5.43	11.46	10.80	8.05	9.58	
Industry	—	9.33	13.63	4.72	9.34	
Colleges & Universities	—	—	11.72	—	11.72	
Other Nonprofit	—	—	13.74	9.74	11.84	
Performer Totals	5.43	10.02	11.24	8.04	9.53	

*Preliminary estimates by NSF.

FIGURE 1. R&D FUNDING AND PERFORMANCE BY SECTOR, 1971-1986

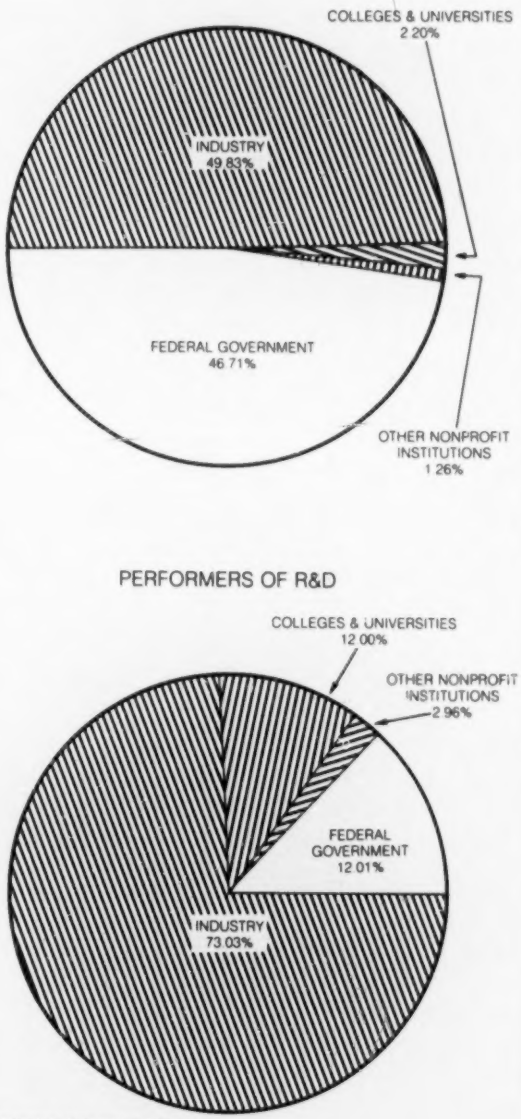


See Tables 1 and 2. 1971-1985 estimates by NSF; 1986 projected by Battelle's Columbus Division.

tions bills for the 1986 Federal budget. Furthermore, since part of the calendar year 1986 will come during the next fiscal year (1987), the budget process throughout this current calendar year will have a continuing effect on total expenditures.

FIGURE 2. R&D EXPENDITURES IN THE U.S., CALENDAR YEAR 1986

The total forecast by Battelle's Columbus Division is $116.8 billion. Distribution shown here is by source and performance.



Source: Battelle's Columbus Divison

Finally, industrial support for R&D will continue to be impacted by previous years' sales and earnings and should be expected to increase at a substantial rate. However, if the tax credit for incremental R&D will in fact expire as originally intended, it is conceivable that the recent rate of growth of industrially-supported R&D will decrease.

Recent actions on that tax credit indicate that it will, in fact, be permitted to expire. However, heavy lobbying efforts may accomplish a "temporary" extension, as differentiated from the permanent extension sought by industry.

In using Table 2, the reader should keep clearly in mind all the distinctions made by the table headings. For instance, in the *column* headed "Industry", we see that the total amount of R&D expected to be performed by industry in 1986 will be $85,265 million. Of this, almost $28,000 million will be funded by Federal agencies, and over $57,000 million by industry. On the other hand, the *row* headed "Industry" indicates that industrial sources of funds are expected to support about $58,200 million of R&D. Of this, $57,300 million will be performed by industry, $551 million by colleges and universities, and $340 million by other nonprofit organizations.

Continued inflation is expected to characterize 1986, although the rate, as experienced in R&D, appears to be declining. In addition, there are many intangibles—partly the increased feeling on the part of both Federal and industrial decision-makers that R&D is vital to long-term economic health—that favor continued increases in support. The NSF estimated that current dollar R&D activity rose by 11.1 percent from 1984 to 1985; we project a smaller increase, 9.53 percent, from 1985 to 1986. As will be shown in connection with the Cost of R&D Index, not all of this increase is expected to be absorbed by inflation.

With respect to the *composition* of R&D activity, the expected pattern continues to be one of year-to-year stability or very slow change—with defense, science- and technology-based problems, considerations of economic development, and foreign competition—still providing the major impetus for change. The proportionate composition of both funding and performance will change very little. The Federal government will account for 46.7 percent of the total funding, as against 49.8 percent for industry. Industry will account for approximately three-fourths of total performance. These two distributions for 1986 are summarized in Figure 2.

The Role of Federal Agencies

Since Federal funding was historically the major source of R&D support (although it has been increasingly outdistanced by industrial support since 1980), the forces likely to affect Federal R&D budgets in Fiscal Years 1986 and 1987 are important in the present forecast. The Budget for Fiscal Year 1986, which began on October 1, 1985, is entirely a product of the Reagan Administration. It continues the emphasis of the earlier Reagan years and sets the stage for what may be significant changes in subsequent years.

The significant increases in defense spending—in terms of both hardware and research—will be continued by the Administration's commitment to new weapons systems and the Strategic Defense Initiative. Furthermore, budget plans through 1988—while certainly subject to modification in the future—set a direction that suggests continued emphasis in this area, although perhaps with a decline in the rate of growth. However, Congressional actions (particularly the Gramm-Rudman budget deficit thrust) can have a strong influence on R&D spending through the remainder of this decade.

Battelle projects $54.5 billion as the most likely level of Federal funding in calendar year 1986. This figure is based upon: (a) recent trends in Federal budgeting, as reflected in NSF data series on R&D funding; (b) the relationship between Federal funding and Federal obligations; (c) the fact that three calendar quarters' funding will be determined by the FY 1986 appropriation; and (d) a strengthening of selected mission agency activities*.

The R&D-Minded Agencies

The big-money agencies in terms of total 1986 R&D funding will include the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), and the Department of Health and Human Services (HHS). Among the smaller agencies, the important suppliers of funds for extramural R&D are the NSF, the Department of Agriculture (DOA), the Environmental Protection Agency (EPA), the Department of the Interior (DOI), the Department of Commerce (DOC), and the Department of Transportation (DOT). Estimated shares for the conduct of R&D in the early proposed budgets for FY 1986 and comparative estimates of the FY 1985 plans are:

	1985 Estimated Authority	1986 Planned Authority
DOD	63.9 percent	68.6 percent
HHS	10.4	9.0
DOE	9.7	8.1
NASA	6.5	6.4
NSF	2.6	2.4
DOA	1.8	1.5
DOT	0.8	0.5
DOI	0.7	0.5
EPA	0.6	0.5
DOC	0.7	0.4

It is obvious from this listing that DOD continues to dominate the Federal scene, accounting singlehandedly for almost two-thirds of the R&D budget. The Big Four (DOD, NASA, DOE, and HHS) account for 92.3 percent of anticipated Federal R&D expenditures. The next six largest R&D-supporting agencies account for only 6.2 percent, and all others combined account for approximately 1.5 percent.

These percentage distributions reflect the continuing impacts of the Reagan Administration. The 1986 structure is still subject to modification by the Congress, although no significant changes are expected.

Functional Categories

Although some of the important R&D agencies are primarily devoted to a single function, many are multifunctional. The NSF list of 16 functional categories, of which the most important have the following shares of estimated 1984-1986 budget authorities:

	1984*	1985**	1986**
National Defense	66.2	68.0	72.7
Health	10.8	10.7	8.7
Space Research and Technology	5.2	5.3	5.3
Energy	5.8	4.7	3.7
General Science	3.7	3.7	3.4
Transportation	2.3	2.0	1.6
Environment and Natural Resources	2.1	2.0	1.5
Agriculture	1.7	1.6	1.3
All Other	2.2	2.0	1.8

*Note that this estimate applies only to spending for the *performance* of R&D, and does not include any spending for R&D *facilities*.

*Actual
**Estimates

The remaining functional fields, each receiving less than .5 percent of the total R&D budget, are: education, training, employment and social services; community and regional development; international affairs; veterans' benefits and services; commerce and housing credit; income security; administration of justice; and general government. Altogether, these smaller fields account for only 1.8 percent of the total.

As had been expected in earlier forecasts, the major increase in R&D expenditures will be confined to that in support of national defense. There will be some modest increases in other areas, and slight increases in many agencies or functional areas. However, as a fraction of *total* Federal R&D, almost all agencies and functional areas—except for defense and space—will show relative (real) declines.

The continued increase in defense-related R&D derives from the development and acquisition of more advanced major weapons systems, and the Administration's commitment to highly sophisticated space-deployed defensive approaches. While the future of such research may well depend upon the types and outputs of arms-control negotiations that recently have been resumed, we expect that part of the research will continue as a part of the "bargaining-chip" process.

As of this writing, however, there is no indication that the Administration has any intention of including the Strategic Defense Initiative (SDI) in this bargaining process. Hence, if defense R&D expenditures are to be slowed, it appears that SDI's losses would not be as great as those of other DOD programs.

The potential deployment of space-situated defensive weapons continues to have some influence on the overall space R&D program. As was noted in recent years' forecast and analyses, the R&D budget for NASA was undergoing change, much of which resulted from the *operational* classification of the Space Shuttle. However, with the emphasis on defensive weaponry and—perhaps more important—the continuation of work on the proposed Space Station, the overall NASA Program will most likely begin to garner a higher proportion of the total Federal R&D budget.

From 1969-70 to 1973-74, year-to-year changes in R&D budgets favored civilian programs over defense/space. Beginning with 1974-75, emphasis has tended to shift back toward defense and space, especially the former. Throughout the 1970s, the funding of energy-related R&D generally grew by larger increments than that of space or of most other civilian programs. It is generally expected that Federally-supported energy-related research and demonstration programs will continue to decline, except for that portion which is in support of direct national defense interests. Some existing DOE programs may be transferred to other agencies, and those which involve short-term and/or low-risk R&D probably will have to be financed by private industry.

Factors Affecting Future Federal Support

There appears to be a continuing effort on the part of the Federal government to increase its funding of R&D, in terms of both support to basic national needs and the broadening of the technological base on which future growth is predicated. National security, reflected in the DOD budget, is seen as a principal driving force in furthering R&D spending. Economic growth, founded upon both basic and applied research, is expected to remain as an objective which requires direct and indirect Federal support, although greater emphasis will be directed toward the latter.

The Federal efforts in energy research will continue to be based primarily on those of basic research that are either inappropriate for industrial support, at this time, or represent such long-term investments that no industrial applications are expected in the near future. As new energy technologies—either in generation or conservation and use—are reduced toward practice, there will be a greater encouragement of industry to take up the effort.

Additional emphasis on high-energy basic physics research may be forthcoming, with plans for the next generation of particle accelerators already under way. There is already a growing interest—expressed generally by the high energy physics community, and specifically by major universities and state governments—in the Superconducting Super Collider. While major construction funds will be required over the next few years, if it is built at all, the operating and research budgets should not be significant within the remainder of this decade and into the next.

While there are indications that industrial support will be growing in the biological sciences (as is evidenced by the major increases in industrial funding at universities), the Federal government will continue to commit substantial resources toward this and allied fields. Budget-trimming efforts, especially as they apply to both health and agriculture, have been largely cos-

metic in recent years; these have been generally offset by Congressional actions that have reinstated various programs in these areas.

Over the past few years, there had been concern that Federal funding of R&D might shift from extramural contract/grant support to intramural research performance, utilizing the capabilities of the extensive Federal laboratory network. In addition, such a concern could just as well be directed at the support of research in the Federally Funded Research and Development Centers (FFRDCs). Over the past year, this concern has been amplified by the recommendations of the Packard Report and the report of the Grace Commission. In each of these cases, some consideration had been given to the "efficiency" of such operations. As of this writing, no actions have been taken in response to either of these investigations, although it is expected that some changes in laboratory operations might be forthcoming. Specifically, consideration is being given to the conversion of presently government-operated facilities to contractor-operated facilities. Such moves might be taken in an effort to increase cost-effectiveness and thereby reduce some actual R&D expenditures.

In viewing the trends in support of the Federal laboratories and the FFRDCs, as shown below, there is little evidence than any shift from extramural programs had been made through 1985. Furthermore, it would be anticipated that any such changes would be relatively small, and slow in coming.

The shares in Federal funding of both the truly intramural and the (university-operated) FFRDCs have, in fact, been declining over the past few years, as shown below:

Percentage of Federal Funds Expended

	Federal Laboratories	Federal Laboratories and University-Operated FFRDCs
1978	28.5	35.7
1979	27.6	34.8
1980	25.9	33.5
1981	25.2	32.6
1982	25.0	31.8
1983	26.2	33.0
1984	27.5	33.7
1985	26.7	32.6

Continued effort is being made to promote the capabilities of the Federal laboratories as resources available to both the Federal and non-Federal markets. As in the recent past, there are conflicts among the various factors that may influence the ultimate outcome of this effort. While Federal regulations permit considerable involvement by Federal laboratories in response to external needs, there also are several real and perceived restrictions. Whether the Federal laboratories will be more heavily involved in R&D performance as a result of actions taken in response to PL 96-480, is yet to be seen. As of this writing, there is little evidence that, taken as a whole, the Federal laboratories are heavily involved in "external" activities*. To the extent that they are, there are no reliable statistics which would support any conclusions regarding the support (on a reimbursable basis) or performance of R&D outside the laboratories specific missions.

Perhaps the most significant factor influencing future Federal government support of R&D is the Gramm-Rudman Bill, a measure designed to make major deficit-reducing cuts in the Federal budget. The issue here is not whether the provisions of the bill are carried out in their present form, but more the apparent mood of the Congress and the Administration. The mandatory actions contained in the Bill will affect all Federal agencies and will affect all manner of procurement, management and operating programs—for materiel, systems, and R&D. In the event that the Bill is enforced, the implications for R&D are perhaps more significant than they are for many other types of Federal purchases.

Specifically, reductions across all agencies would more likely be made with individual agency discretion. While all spending would be subject to across-the-board reductions, it is likely that the "discretionary" nature of R&D would be more seriously affected than ongoing operational programs. Hence, R&D may be expected to suffer higher percentage cuts in all departments, with the total reduction in Federal-supported work exceeding the general targets which are inherent in the formulas of Gramm-Rudman.

There is no question that enforcement of the Bill will run into much political infighting, especially in an

*The roles and operations of the Federal laboratories may be influenced by the recent Packard Report (and the Federal agency response) as well as the expansive report of the Grace Commission. Furthermore, any conversion to contractor-operated facilities could significantly affect the transfer of technology to the private and non-federal public sectors.

election year. Already, Department and Agency directors are mounting campaigns that would exclude them from the provisions of the Bill, and the constitutionality of the Bill will be tested in the Courts. In the spirit of Executive/Legislative cooperation, it is expected that a diluted version of the Bill will be enforced, with implications for R&D expenditures, and that efforts to promote full enforcement will continue throughout the next few years. It is in this sense that one needs to be less concerned with the Bill itself than with the general mood of the Congress and the Administration.

Alternatively, any real failure of Gramm-Rudman—and this failure could be recognized and acknowledged by the time that the Administration submits its 1988 Budget (February, 1987)—could serve as the trigger for the "last resort" tax increase required in order to approach a balanced budget. Coming as it would in a non-election year, there is a greater likelihood of passage, albeit with the negative impacts that may effect economic growth and industrial support of R&D.

The Role of Industry

NSF data indicate that industrial support has been greater than Federal support since 1980 and Battelle projects industrial support of R&D to continue to be greater than that from the government in 1986. As has been the case in all previous years, industry will be by far the predominant R&D performer.

During 1985, the NSF has estimated that industry will provide 49.9 percent of total funding and perform 72.7 percent of all R&D work (see Table 2). Battelle's forecast for 1986 changes these shares almost imperceptibly to 49.8 and 73.0 percent, respectively.

The NSF data base indicates that industry also has been the fastest growing sector. Table 3 compares sectoral growth rates for the nine-year interval 1976-85. In connection with this table, attention is called to two relationships. First, every sector except the other nonprofits tends to grow somewhat slower as a performer than as a source of funds.* And second, in the case of the government, the fact that this differential exists also indicates a lack of support for the thesis that Federally funded R&D is being transferred to Federal laboratories.

*Although this appears to be a mathematical anomaly, it results from substantial differences in the two weighing patterns.

TABLE 3. SECTORAL GROWTH RATES IN FUNDING AND PERFORMING R&D, 1976–1985

	1976 = 100.0%	
Sector	**Source**	**Performer**
Total United States	273.2	273.2
Federal Government	249.9	230.5
Industry	300.7	287.1
Colleges & Universities	284.0	258.4
Other Nonprofit	219.2	232.6

Source: Derived from Table 1.

Battelle projects considerable differences among the 1985-86 sectoral growth rates. Total R&D expenditures are expected to grow by 9.5 percent; industrial funding and performance are both expected to increase by 9.3 and 10.0 percent, respectively.

Industrial funding is expected to rise from an NSF estimated level of $53,210 million in 1985 to $58,180 million in 1986. Industrial performance will rise from $77,500 million to $85,265 million. As will be seen later, this total performance implies a definite increase in *real* industrial R&D activity (5.19 percent).

Industrial research, as it applies to the accomplishment of industrial and governmental objectives, is both a means to an end and an end in itself. While the continuing profit motive in a competitive marketplace spurs R&D for individual industry's benefit, so also does the industrial system provide a mechanism for the execution of programs of high national priority. In view of: (a) the continuing emphasis on innovation; (b) the application of advanced control technology to mature industries; and (c) continued tax incentives for industrial R&D, Battelle's 1986 forecast continues a new area of analysis, namely, the comparative Federal and industrial funding of R&D in major groups of industries.

Using data derived both from NSF sources and from interpolation or extrapolation of the McGraw-Hill surveys, we have estimated the degrees to which industrial and Federal funds will support industry R&D performance (see Table 4).

This distribution between Federal and industrial funds is, unfortunately, somewhat misleading for it does not address the more critical question of support of R&D among different lines of business. With R&D expenditures grouped according to major SIC classifications, it is not possible to distinguish, for example, electronics research performed by a well-known electronics

company from that performed by a subsidiary of a major company whose principal product line (and SIC classification) falls into an entirely different category. Conversely, this determination does not isolate, for example, research in chemicals which is performed within the rubber or petroleum industries.

As a special added feature to this year's Forecast, we shall deal with a different aspect of this problem in the section entitled Estimation of Sectoral R&D Activities.

With reference to Tables 2 and 4, the performance of R&D by industry will be financed either by the Federal government or by industry itself. Industrially funded work will mostly be done by industry either internally or contracted to other industry, although a very small amount (less than 2 percent) will be done extramurally by universities and other nonprofit institutions. The nonmanufacturing industries do relatively little R&D and, as noted in Table 4, approximately 48 percent of the support for this activity is provided by the Federal government. In contrast, R&D is more heavily self-funded by (and in) the manufacturing industries where, on the average, about 31 percent of the total performance is supported by Federal funds.

The leading industry in the nation for R&D will be the aerospace industry, projected to do approximately $21 billion, with over three-fourths of its funds from Federal sources. In second place will be the electrical machinery and communications industry, projected to spend almost $17 billion, of which 36.7 percent is Federally funded. Since 1980, these two major sectors have dominated and interchanged between first and second place and are expected to dominate in the foreseeable future. Further appropriations for defense systems, as well as anticipated growth in the computers and communications industries, are expected to continue the dominance of these two broad industrial classes.

Aside from aerospace, where Federal support of R&D is dominant, there are no industry groups in which more than half of the R&D performance is expected to be supported by Federal grants and contracts. In addition to electrical machinery and communication and rubber products (20.5 percent), no other industries receive as much as 19 percent of their funding from Federal sources.

Finally, we call attention to the fact that the total industry fundings shown in the third column of Table 4 make no distinction between R&D performed in-house or that contracted out to other industrial firms.

TABLE 4. ESTIMATED SOURCES OF FUNDS FOR R&D BY BROAD INDUSTRIAL CLASSES, 1986

(Millions of Current Dollars)

	Federal Funds	Industry Funds	Total Funds	% Federal
Aerospace	15,850	5,024	20,874	75.93
Electrical Machinery and Communications	6,161	10,633	16,794	36.68
Machinery	1,482	9,553	11,034	13.42
Chemicals	566	8,422	8,988	6.29
Autos, Trucks & Parts, & Other Transportation Equipment	953	7,263	8,216	11.59
Professional & Scientific Instruments	1,129	6,402	7,530	14.98
Petroleum Products	152	2,245	2,397	6.33
Rubber Products	248	961	1,209	20.48
Food & Beverage	0	1,085	1,085	0.00
Paper/Pulp	0	816	816	0.00
Fabricated Metals & Ordnance	83	669	752	11.01
Stone, Clay & Glass	27	701	728	3.69
Iron & Steel	133	571	705	18.92
Nonferrous Metals	68	583	651	10.41
Textiles	0	184	184	0.00
Other Manufacturing	35	1,011	1,047	3.37
Total Manufacturing	26,885	56,124	83,009	32.38
Nonmanufacturing	1,092	1,164	2,256	48.39
TOTAL	27,977	57,288	85,265	32.81

Factors Affecting Future Industrial Support

Over the past few years, industrial spending on R&D has increased significantly although—as anticipated in last year's Forecast, the rate of increase in 1986 will be slightly lower. Recent spurts in industrial support have been the result of a healthier economy during this decade, increased sales and profits (both early indicators of R&D fund availability), relaxation of perceived barriers to cooperative research, and—to a small degree—the R&D tax credit enacted in 1981.

These much-heralded credits have been the subject of considerable recent debate and heavy lobbying efforts. Arguments have been forwarded which "prove" the benefits that have been achieved. Conversely, the generous definitions of "R&D" have also been used to cast a shadow on the deductions that have been taken and have been used to identify the abuses of the original intent. If there has been any real impact on funding levels that is specifically attributable to the tax credit, it has been only within the past two years. Given the time-lapse between R&D planning and R&D spending, it would not have been expected that the first one or two years of the credit period would have had a significant effect.

It is not expected that that future Congressional action on the tax credit will have a significant impact on industrial R&D spending, regardless of which direction this action takes. For those industries or firms which have become acculturated to the concept of R&D and who have adopted a continuing R&D posture, the tax credit will not influence the decision to maintain and pursue R&D as a strategy for growth, diversification, and survival. Conversely, those who view the credit simply as a tax credit—especially with the more restrictive definition of allowable deductions—are not likely to take advantages of the provisions of the tax code.

In any discussion of the tax credit, a more important question should be addressed: namely, to what extent is R&D spending influenced by the short-term tax credit, as opposed to the R&D spending which is the result of the realization that R&D is necessary for its contribution to long-term profitability and survivability?

Much has been written regarding the competitiveness of U.S. industry, particularly with regard to the large-volume and highly visible items such as automobiles, steel, textiles, shoes, and other products and commodities. To no small degree, industry has responded to a number of the challenges through an intensified research effort, believing that an expansion of knowledge is one of the keys to long-term viability. The total U.S. industrial research enterprise has grown to be unequalled throughout the world, spurred on by both industrial and government policies and needs. There are, however, major shortcomings in industry's ability or willingness to implement that knowledge. The combined complications of tax advantages and disadvantages, substantial investments required for upgrading of old and obsolete plant and equipment, competitiveness for investment dollars and the associated interest rates, the devotion of resources toward manipulation rather than innovation, competing and often devisive goals of labor and management, and the short-term perspective of all parties involved does not auger well for future economic strength and growth.

Added to this is the propensity to look to government to resolve problems through bailouts, import quotas, and other preferential treatment—coming at a time when government seeks to extricate itself from the massive problems associated with the growing budget deficit. It is apparent that industry's problems will have to be addressed more by industry itself; that dying industries will have to either change their habits or change their business; and that government assistance will come more in the form of not what government will do, but in the form of what government permits others to do. Perhaps the most positive actions that government has taken along this line have been in the forms of permitting more cooperative research and in a continuing effort to define and implement new patent policies.

An additional note should be included regarding the building of new institutional relationships between industry and other parties. As noted in last year's Forecast, State and—to a lesser extent, local—governments have been taking a more positive attitude toward increased R&D-based economic activity. Local governments' options are somewhat limited to the "creation of an environment", and include tax relief or deferral programs for new industry. (The extent to which even this modest approach can be continued will be influenced by the soon-to-be-discontinued revenue sharing which has benefitted communities for over a decade.) But State governments have actually put hard cash into R&D, with part of this being directed toward the development of new businesses and the matching of industrial and university (and other) resources.

In addition, universities themselves have been expanding their efforts to promote industrial parks, providing both land and incubator facilities for start-up businesses, and stressing the applications of university-based research. And, finally, there are continuing efforts on the part of Federal laboratories (both government-operated and contractor-operated) to link with industry. While such relationships are sporadic and slowly growing, the influence of the Packard Report (which addressed, among other issues, the effectiveness of existing technology transfer activities) is expected to be felt in the commercial implementation of federally-held technology.

The Role of Academic and Other Nonprofit Institutions

Nonprofit institutions—colleges, universities, and other types—both fund their own research and conduct research funded by Federal agencies, and/or industrial firms. It is generally conceded that a significant portion of all basic research is conducted in this sector, as well as some of the longer maturing applied research.

In 1960, the academic and other nonprofit institutions financed from their own resources (including endowments and direct state and local funds) approximately 2 percent of all R&D (see Table 1), while actually performing over 9.5 percent of the total. For 1986, Battelle forecasts (see Table 2) that these same nonprofits will provide 3.5 percent of all funding and will perform almost 15 percent of the total. These percentages are slightly higher than the corresponding ratios for the 1985 NSF estimates.

The growth in nonprofit R&D performance has been accompanied by minor shifting within the nonprofit sector. In 1960, the academic community (universities and colleges) accounted for 55.4 percent of total nonprofit funding and performed 78.1 percent of the nonprofit total. For 1986, Battelle forecasts 63.6 percent and 80.2 percent, respectively. A significant portion of the increase in academic support and performance derives from the increase in major industrial support ("directed endowments") associated with specialized areas of research such as electronics, artificial intelligence, and biological sciences.

Attention is called to the part played in these developments by the nonacademic nonprofit organizations. There are two distinct groups of these "other" nonprofit organizations, the *foundations* which exist primarily for charitable purposes and the *nonprofit research centers* which may or may not perform under contract. The first group funds a great deal of research, primarily through the mechanism of grants; and these grants go both to members of the academic community and to other nonprofit centers. The second group acts in three ways: a member may perform as a foundation; it may fund its own research performance; and/or it may perform under contracts (with government, industry, or other nonprofits).

From 1965 to 1980 other nonprofit performance has fluctuated slightly between 3.3 and 3.7 percent of total R&D. Since then, this sector has declined to less than 3 percent. For 1986, Battelle estimates that the other nonprofit sector will comprise 2.96 percent of total R&D performance. Furthermore, we estimate that 53.4 percent of other nonprofit funding will go to colleges and universities, with the remaining 46.6 percent being spent by the other nonprofit sector itself. This division of support is approximately the same as that estimated by NSF for calendar year 1985.

The total R&D performance in the other nonprofit sector is not increasing as rapidly as in other performing sectors. However, a word of clarification is appropriate. As noted above, this sector is quite diverse in the character of the constituent organizations. As performers of R&D, the establishments within this sector range from institutions such as Battelle (engaged in a broad spectrum of programs in the classic science and technology fields as well as in economics and other social sciences) to small nonprofit firms that act as delivery mechanisms and research arms for Federal, state, or local government agencies, especially for social programs.

The activities of these latter types of organizations have been significantly curtailed in recent years. Hence, it is not unexpected that the aggregate of nonprofit performers should display smaller-than-average growth rates, or, in fact, real declines in comparison with other performing sectors.

It also should be noted that historical data for the other nonprofit sector has some serious shortcomings, especially with regard to recent years. The NSF has not conducted detailed surveys of nonprofit funding and performance for quite some time. The recent data are no better than "estimates based upon estimates", and forecasts developed from such data have similar uncertainties.

Finally at this point, attention is called to the variety of forms taken by industrial support for academic

R&D. In addition to contracts or grants to support research on industrial problems (this is the "industry funding of colleges and universities" shown in Table 2) there is another form of support, not yet reported in detail by the NSF, that must be noted. These industry/university arrangements take a form that more nearly resembles a "directed endowment" rather than either a specific research contract or a general gift. The large multiyear programmatic grants are then accounted for in terms of college and university self-funding.

Although major endowments of universities or individual departments may accomplish objectives that are important both to academia and to industry, not all such partnerships have been completely welcomed. On the positive side, these major programs may foster advanced university research and industrial access to faculty and graduate students. Furthermore, they provide a mechanism for promoting further graduate research and education—countering a trend that has been disturbing to both the universities and industry.

On the other hand, there continues to be some reluctance toward the development and concentration of university research programs in areas closely tied to potential commercial ventures. The academic community may be willing to develop patents and possible commercial spinoff industry, but there is certainly less enthusiasm for creating situations in which external forces might dictate department policy. Industrial reluctance for these arrangements derives from the difficulty of maintaining proprietary claims and confidentiality with respect to the findings of industrially sponsored research. The slow, but continuing, growth of this form of funding suggests that, at least to this time, the "mutual concerns" either have not developed or have been resolved.

The Cost of R&D Inputs

From an economic point of view, inflation can be defined as a general rise in the price of goods and services that is not offset by corresponding increases in quality. If the prices of everything tend to rise together, slowly, and in the same proportions—and if individual incomes also rise in those same proportions—the relations between money and goods/services change, but in a fashion which is detrimental mainly to the holders of such fixed-dollar obligations as life insurance. On the other hand, when the prices of things bought with income rise faster than the incomes, structural imbalances occur which may be quite painful to particular sectors of the economy.

Goods Versus Services

Most considerations of prices tend to take place within the context of goods' prices, i.e., the prices of tangible things. The very tangibility of goods makes it possible both to measure the quantity of their output and to estimate, within reasonable limits, changes in their quality. Thus, with respect to goods, there usually is agreement as to whether or not costs are rising faster than output, or prices faster than quality—that is to say, we tend to have general agreement that inflation is or is not occurring in the goods-related economy.

Services, on the other hand, are intangible. Therefore we usually have greater difficulty achieving agreement that, in terms of any meaningful measure, the quantity or quality of service output is rising or falling. As a result, our only measure of many types of service output is the total amount of money that we pay for them—and that is a function of price and quantity, with no account taken of quality.

R&D, by definition a part of the "knowledge industry", is primarily a service activity, despite the fact that much of it ultimately becomes embodied in products. For this reason, we have no agreement as to what can be termed a "unit" of R&D output; and we, therefore, cannot ascertain whether or not the "price" of R&D *output* is rising or falling. We can price R&D *inputs,* however, and for that reason most discussions of the cost of R&D tend to be couched in those terms. Battelle has not yet given up hope of achieving a measure of R&D output, and from time to time has undertaken investigations which may lead to the quantification of at least some kinds of R&D output. Nevertheless, such a measure is not now available and the discussion which follows must be in terms of input costs.

In viewing the costs of R&D performance, it is tempting to contrast the "inflation" in R&D with the commonly used Consumer Price Index (CPI)—the factor which provides a measure of general inflation—or to use the GNP deflator, as NSF does. To do so misses three basic points distinguishing R&D from the more general set of purchases. First, the CPI is based upon the average "marketbasket" purchased for general consumption, and the GNP deflator covers a somewhat broader range. However, purchases by R&D performers are from a much more specialized collection of goods and services.

Second, the education of scientists and engineers has a built-in bias for the acquisition and use of more

sophisticated (and, hence, generally more expensive) materials, devices, and systems required for the conduct of research. Were it not for this factor of the research culture, technological advance would not be so rapid.

Third, and perhaps most important of all, the very nature of research is such that the problems addressed by researchers are increasingly more difficult. The easy questions are always solved first; and the effort necessary to make incremental gains in the understanding and application of science and technology is ever-increasing. Thus, it would be expected that the "inflation rate", as applied to the conduct of R&D, would increase more rapidly than that of the average consumer purchases.

The "Cost of R&D Input" Index

In the absence of a measure of R&D output costs, many organizations, including the NSF, use the GNP deflator (from the national income and product accounts) as an indicator of changes in R&D costs. This index responds to the costs of both goods and services. R&D costs are made up primarily of service costs, however, for which reason Battelle researchers feel that the GNP deflators probably have misstated recent rates of inflation with respect to R&D.

Several attempts have been made in the recent past to determine the input mixes of typical R&D activities and to price each input, thereby generating standard weighted price indexes for R&D. To date, this approach has not been very productive, although such efforts continue and may eventually achieve success.

A pioneering effort at more directly measuring trends and fluctuations in the cost of R&D was made by Helen Milton* beginning in 1966. Using information supplied by representative R&D performers Milton, compiled data on the total dollar cost of R&D per technical (professional) man-year.** Her series of cost indexes ended with 1970, using 1950 as the base year. Between 1970 and 1979 Battelle extended the Milton Index series by means of annual estimates. Finally a new series of R&D cost indexes was introduced in the 1980 Battelle Forecast and Analysis. This new series, while conceptually similar to the Milton Series, is based upon a different body of data and does not show precisely the same year-to-year changes as the Milton Series and our earlier extensions thereof.

The Battelle Cost of Research Index, displayed in Table 5, is based upon two series regularly published by the NSF: (a) the R&D performance figures, by Sectors, that have already been discussed in connection with the Source/Performer Matrix (Table 2); and (b) estimates of the full-time equivalent numbers of R&D scientists and engineers employed by each performing sector. The ratio of costs to scientists/engineers for each sector provides the basis for the sectoral subseries, which are then weighted and combined into the all-sector average.*

As derived from Table 5, Battelle's best estimates of recent increases in the total index are for 6.8 percent for 1982-83, 7.7 percent for 1983-84, and 6.1 percent for 1984-85. We expect the cost of R&D to increase by about 4.9 percent between the estimated 1985 level (250.85) and the forecast level for 1986 (263.16) with the estimates stated in terms of the 1972 base.

Sector Comparisons of R&D Costs

During the interval 1972-86 costs of all R&D, as an average, are estimated to have risen by 163.16 percent. Increases in the individual performing sectors are expected to be: Federal government, 193.13 percent; industry, 152.96 percent; colleges and universities, 202.79 percent; and other nonprofit, 174.86 percent. As noted, the 1985-86 cost increase for all R&D is estimated to be 4.91 percent. By sectors, the increases are estimated as Federal, 3.07 percent; industry, 4.59 percent; colleges and universities, 9.16 percent; and other nonprofits, 6.53 percent.

Trends in Real R&D Effort, by Sectors

If we take total expenditures and sector performance figures from Tables 1 and 2 and deflate them to constant 1972 dollars with the corresponding index numbers from Table 5, we can make parallel comparisons for each of the four performing sectors. These are shown in Table 6 and graphed in Figures 3 and 4.

*See Helen S. Milton—"Cost of Research Index, 1920-1970". *Operations Research*, 20, 1-18 (1972).

**Milton said on p. 1, "The 'technical man' is the professional scientist or engineer, plus his support".

*As noted, in the text, the Battelle Cost of Research Index is derived from both NSF data and our own projections. Variations in the historical cost index, as reported in these Forecasts, are generally attributable to changes in the NSF data, which are continuously adjusted. Note, for example that the *Patterns* report for 1982 contains adjustments in data dating back to 1970, and the *Highlights* report, noted earlier, contains adjustments in data dating back to 1977.

In current (undeflated) dollars, total U.S. R&D expenditures have risen in every year of the period, even though the rate of increase fell sharply between 1969 and 1971. But the deflated (real effort) series before 1978 reached its peak in 1969, declined between 1969 and 1973, and moved generally sideways until 1977, when it exceeded $30 billion for the first time in 10 years. We expect real R&D effort in 1986 to increase by 4.4 percent over 1985 and to reach a level that is 45.1 percent above its 1969 peak.

When we shift our attention to the performing sectors, we find that the recent upward drift of real R&D activity results from the behavior of the private sectors. The downturn or flat behavior in real expenditures that began after 1968-69 is clearly reflected by every sector. However, deviations in sector behavior emerged later, especially since about 1975. In government, the real performance series has recovered only slowly from its 1977 minimum and has not yet equalled its 1969 peak.

In the private sectors, industry reached its real low in 1973 and has since risen by 74 percent to its highest recorded value. The academic community reached its low in 1973. Since then, its real performance has risen by over 38 percent and now stands well above the 1968 value. Other nonprofit institutions' real performance declined slightly from 1968 through 1970. Since that time it has risen by 35.8 percent to a level of 33.4 percent above the 1968 peak.

Finally, we turn to the data of Table 6 and the curves of Figures 3 and 4 to see the dramatic differences in the R&D trends among the four performing sectors. Since the lull of the early 1970s, industrial performance, funded by both government and industry, has been

TABLE 5. BATTELLE COST OF RESEARCH INDEX* BY PERFORMING SECTORS, CALENDAR YEARS 1960–1986 (1972 = 100.00)

		Performing Sectors			
Year	Total U.S.	Federal Government	Industry	Colleges and Universities	Other Nonprofit
1960	59.17	49.22	62.57	46.50	72.55
1961	60.68	51.45	63.28	52.64	74.47
1962	62.89	54.81	64.64	59.25	77.11
1963	67.12	56.59	69.27	65.79	76.18
1964	71.76	67.48	72.35	73.35	75.07
1965	73.40	70.22	73.71	75.36	76.29
1966	77.09	70.59	78.17	78.78	80.69
1967	78.54	71.65	79.51	81.46	82.11
1968	81.33	72.09	82.58	85.43	86.29
1969	83.84	71.75	85.93	85.34	93.97
1970	86.43	84.78	86.05	87.66	98.94
1971	90.53	89.88	90.10	92.00	97.58
1972	100.00	100.00	100.00	100.00	100.00
1973	109.09	105.55	109.89	110.53	104.71
1974	116.51	109.37	118.19	115.22	120.42
1975	120.62	118.48	120.33	123.17	127.04
1976	130.16	128.47	129.96	132.29	134.08
1977	137.78	135.61	137.15	142.53	142.64
1978	148.20	148.05	145.53	161.63	153.14
1979	161.71	161.09	158.25	181.93	166.03
1980	174.02	163.23	171.68	199.16	179.02
1981	190.50	179.10	188.00	217.90	195.06
1982	205.50	199.77	203.27	226.27	205.66
1983	219.54	231.62	214.52	239.66	222.74
1984	236.40	267.55	228.60	255.34	243.30
1985	250.85	284.89	241.85	277.38	258.01
1986	263.16	293.63	252.96	302.79	274.86

*Costs of performing R&D per scientist/engineer (full-time equivalence).
Source: Estimated by Battelle from NSF and Battelle data.

largely responsible for the real growth within the R&D enterprise. Using the same performance deflators as applied to the sources of funds, it is seen that over the past decade, industrial support of R&D has increased at an average compounded rate of 5.38 percent per year, while Federal support has increased at 1.73 percent per year on average.

The behavior exhibited in Figures 3 and 4 suggests that the real growth in R&D—and the economic development and expansion that result from it—has come from the applied research supported and performed by private industry. However, one cannot overlook the fact that such applied research and development must rest on, and evolve from, the basic research foundation—an activity that is primarily supported by the Federal government (almost 67 percent).

Over the past few years, Federal support has tended to shift toward more "development" and less basic

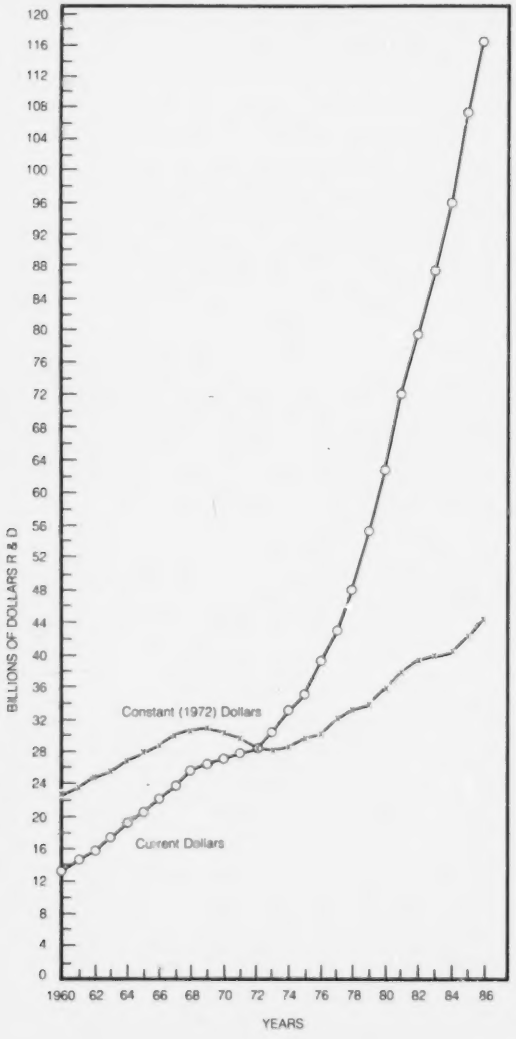


FIGURE 3. TOTAL R&D EXPENDITURES, 1960-86, IN CURRENT DOLLARS AND CONSTANT DOLLARS (1972 = 100%)

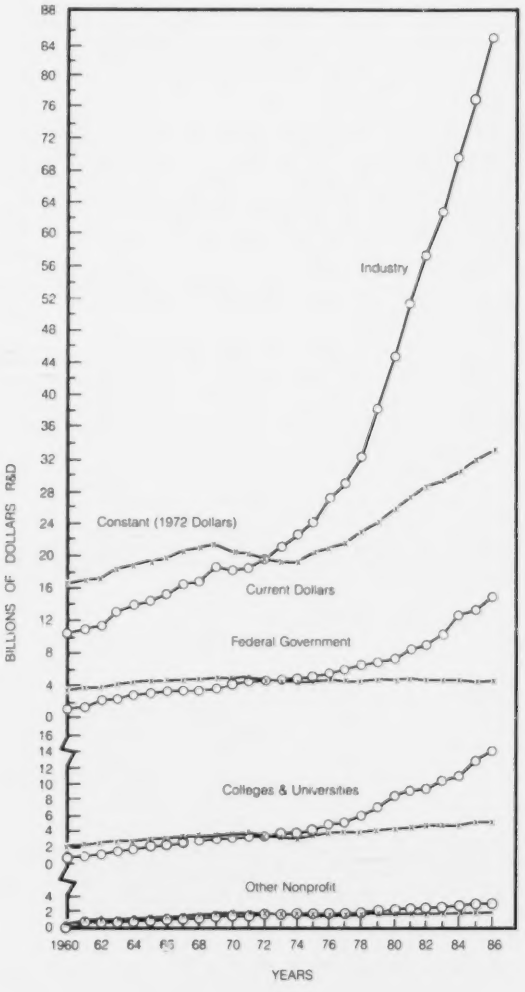


FIGURE 4. R&D EXPENDITURES BY SECTORS, 1960-86, IN CURRENT DOLLARS AND CONSTANT DOLLARS (1972 = 100%)

and applied "research". The Federal government is still the major supporter of basic research, and trends in the Federal budget indicate that this support will continue to be strong. In addition, there is a continuation of basic research support by industry. However, the volatility of those indicators (sales, profits, cash flow) which influence industrial R&D budgets precludes the stability needed for long-term planning. Policy- and budget-makers in all funding sectors should note very carefully the trends in basic research, for the conduct of such research forms the basis for future economic vitality and competitiveness.

Thus, the Federal government, in any attempt to maintain the vitality of our technology-based and technology-influenced economy, should continually reexamine its policies relative to (a) the support of R&D, (b) the roles of the public and private sectors, (c) the factors which enhance or impede the progress of science and technology, and (d) the commitment to science education at all levels. Such examination will most likely be clouded by pressures imposed by budget-cutting activities and the politics of short-term gains.

A Look Toward 1987 and the Future

While former issues of the Battelle *Forecast and Analysis* (through the 1983 edition) had been confined to considerations of just the forthcoming year, well-established commitments by both the Federal government and industry permit a longer look at the R&D forecast. Judging from recent trends in government spending, long-term budget commitments (tempered by budget-cutting activities), and the existing overall business climate, it is estimated that 1987 sources for R&D will be:

TABLE 6. CURRENT AND CONSTANT DOLLAR (1972=100) R&D EXPENDITURES IN THE U.S., 1960–1986, BY PERFORMERS

(All Amounts in Millions of Dollars)

	Total U.S.		Federal Government		Industry		Colleges and Universities		Other Nonprofits	
Year	Current	Constant	Current	Constant	Current	Constant	Current	Constant	Current	Constant
1960	13,523	22,854	1,726	3,507	10,509	16,795	1,006	2,163	282	389
1961	14,316	23,592	1,874	3,642	10,908	17,237	1,173	2,228	361	485
1962	15,394	24,474	2,098	3,827	11,464	17,734	1,374	2,319	458	594
1963	17,059	25,415	2,279	4,027	12,630	18,232	1,611	2,449	539	707
1964	18,854	26,274	2,838	4,205	13,512	18,674	1,904	2,596	600	799
1965	20,044	27,307	3,093	4,405	14,185	19,243	2,103	2,790	663	869
1966	21,846	28,335	3,220	4,561	15,548	19,889	2,345	2,976	733	908
1967	23,146	29,470	3,396	4,740	16,385	20,607	2,594	3,184	771	939
1968	24,605	30,251	3,494	4,847	17,429	21,104	2,868	3,357	814	943
1969	25,631	30,568	3,503	4,882	18,308	21,303	2,950	3,457	870	926
1970	26,134	30,235	4,079	4,811	18,067	20,994	3,072	3,504	916	926
1971	26,676	29,465	4,228	4,704	18,320	20,331	3,216	3,495	912	935
1972	28,477	28,477	4,590	4,590	19,552	19,552	3,383	3,383	952	952
1973	30,718	28,157	4,762	4,512	21,249	19,337	3,701	3,348	1,006	961
1974	32,864	28,207	4,911	4,490	22,887	19,364	3,888	3,374	1,178	978
1975	35,213	29,191	5,354	4,519	24,187	20,099	4,396	3,569	1,276	1,004
1976	39,018	29,975	5,769	4,490	26,997	20,773	4,876	3,686	1,376	1,026
1977	42,783	31,051	6,012	4,433	29,825	21,745	5,451	3,824	1,495	1,048
1978	48,129	32,475	6,811	4,576	33,304	22,883	6,342	3,924	1,672	1,092
1979	54,933	33,970	7,417	4,604	38,226	24,154	7,296	4,010	1,994	1,201
1980	62,593	35,969	7,632	4,676	44,505	25,922	8,306	4,170	2,150	1,201
1981	71,839	37,710	8,425	4,704	51,810	27,557	9,304	4,270	2,300	1,179
1982	79,301	38,589	9,141	4,576	57,995	28,530	9,740	4,304	2,425	1,179
1983	86,555	39,424	10,582	4,569	62,816	29,281	10,482	4,374	2,675	1,201
1984	95,925	40,576	12,300	4,597	69,250	30,292	11,400	4,465	2,975	1,223
1985	106,600	42,494	13,300	4,668	77,500	32,043	12,600	4,542	3,200	1,240
1986	116,760	44,368	14,022	4,775	85,265	33,706	14,016	4,629	3,457	1,258

Source: Current dollar figures from Tables 1 and 2, deflated in terms of Battelle Cost of Research Index of Table 5.

Federal government	$ 55,890 million
Private industry	60,720 million
Colleges & Universities	2,680 million
Other Nonprofit Organizations	1,510 million
TOTAL	$120,800 million

In addition, it is estimated that 1987 expenditures of R&D will be distributed among the four performing sectors as follows:

Federal government	$14,270 million
Private industry	88,470 million
Colleges & Universities	14,540 million
Other Nonprofit Organizations	3,520 million

The overall 3.5 percent increase in funding and performance (expressed in constant 1986 dollars) will be unevenly spread among funding and performing sectors. It is expected that funding and performance by both the Federal government and the Other Nonprofit sectors will increase more slowly than average, while industrial and university funding and performance will increase more rapidly.

The trends which pointed to a slowdown in the rate of growth, noted in last year's Forecast, are expected to continue. While Federal funding of R&D had increased substantially—largely influenced by defense programs—the growing Federal deficit was beginning to take its toll. Although neither the Congress nor the Administration had been willing to really come to grips with the problem, it was inevitable that new, and perhaps unpopular, actions would be required: the formula of huge defense buildups plus reduced taxes plus a balanced budget could not, and did not, occur. To a not insignificant degree, the passage of the Gramm-Rudman Bill has accomplished the "best" of all possible worlds —it has forced cutbacks in expenditures while giving the appearance that no one (especially elected officials) has to bear the responsibilities for so doing.

As a result of the actions which are anticipated to be taken in response to the mandated formulae for budget reductions, the rate of growth will continue to slow, although some real growth in Federal spending will occur.

The picture regarding industrial R&D growth is a little more difficult to decipher, since other kinds of forces have an influence. Federal policies certainly affect industrial decisionmaking, and action or inaction relative to increased private and corporate taxes, limited import duties or other protectionist measures, R&D tax credits, patent policy, and cooperative research will affect the industrial commitment to R&D, as they have done in the past. These actions generally act more as small perturbations on the more important driving forces for industrial support of research and development, namely, the need to respond to competition (both foreign and domestic) and the availability of funds, deriving from earlier years' sales and profits.

Increases in university self-funding and performance in the near future are, in part, a consequence of increased industrial actions of the recent past. The relaxation of apparent barriers to industrial cooperation created a funding mechanism which has infused substantial additional resources to the college and university sector. Counted, as they are, as the sectors "own funds", this form of R&D support and performance will most likely continue to grow slightly over the next few years. However, it is also quite possible that a period of disenchantment will set in, particularly if either of two factors comes into play: (1) the universities feel an encroachment upon their independence and sovereignty; or (2) supporting industries are unable or unwilling to reduce research to applications and profit. If either of these conditions comes to pass—and the next five years is the critical period—the industry/academia honeymoon will likely appear to be merely an anomaly in the historical picture of long-term relations.

As would be expected, there is continued support by all sectors for the concept of research emphasizing the exploitation of scientific and technological information, especially as it impacts on the strength of the U.S. economy and the profitability of individual enterprises. On the other hand, there continues to be little support for those programs addressing the non-technological factors relating to the future impacts of technology. To be sure, science education programs that suffered during the early years of the Administration show some signs of recovery. However, much has yet to be done to provide the kinds of incentives necessary to retain or maintain strong educational programs in the pre-college area.

The total support of R&D involves an obvious "partnership" between government and industry in terms of both the levels of support and the division among basic research, applied research, and development.

In addition, the development of technologies that have obvious applications in defense, space, health,

and other Federal agenda items, have (and have had) significant implications in terms of industrial growth and competitiveness. Thus, there are continuing efforts made to promote greater cooperation between Federal laboratories and the private sector. The extent to which these efforts have paid off is less than had been anticipated or hoped; in many respects, the lack of "success" relates to a lack of understanding of the incentives of both the providers (Federal laboratories) and the users (private industry). One should not, of course, take this to be an indictment of either side of the exchange process.

As the concepts of "efficiency" and "effectiveness" take different forms within the Federal government, a combination of initiatives has been pursued. As noted elsewhere in this Forecast and Analysis, much emphasis has been given to the bottom-line objective of reducing Federal expenditures and balancing the Federal budget. There are, to be sure, many different approaches to these goals, with drastic programmatic cuts and significant tax increases being the most visible and vocal means that have been suggested. In addition, much play has been given to a reduction of fraud, waste, and abuse, to the collection of debts owed to the government, and to the streamlining of government operations.

Within this last category, the output of the Grace Commission and the Packard Report, addressing general government and government laboratories, respectively, is receiving mixed response. Large reductions in expenditures, as suggested by the Grace Commission, may very well be possible. However, there are entrenched policies, procedures, careers, and "sacred cows" which will stage massive campaigns against almost every recommendation. To borrow a phrase which is more often reserved for the lack of industrial commitment to plant improvement, the "inertia of sunk capital" is such as to thwart major—and certainly sudden—change in the bureaucracy. On paper, the drive toward efficiency has great conceptual support; in practice, the implementation will come very slowly, if at all, and more through attrition than by fiat.

Carrying the argument a step further—for there are many implications regarding R&D and economic growth—the concept of privatization, from resource maintenance to selected government operations, has, as pointed out in the Packard Report, extended to the expansion of the GOCO concept. Specifically, that is the conversion of existing Government Owned/Government Operated (GOGO) facilities—such as most of the Federal laboratories—to being Government Owned/Contractor Operated entities.* The rationale is multifold, but two important features emerge. First, it is assumed that private sector motivations and management techniques would lead to more efficient operations. And, second, it is assumed that "the industrial connection" would provide both the mechanisms and the incentives for the accelerated transfer of technology. For the latter to occur, existing patent licensing procedures may have to be modified.

There are, of course, many barriers to the privatization of any government services or facilities, and each program or facility would have to be investigated on its own merits. However slow in coming, the potential for more private sector involvement in the R&D side of government can have a significant impact on the future conduct, funding, directions, management, and exploitation of the R&D resources of the country.

The national commitment to continued support and growth of R&D is based upon the (usually nonquantifiable) observation of the positive impacts of past actions. Each funding and performing sector—individually and in concert with the others—has made major contributions to the economic strength and security of the nation. Furthermore, this cooperative effort has permitted the assumption of a pre-eminent position among the nations of the world.

But as technological advances are made, a greater effort should be pursued to look at the long-term implications of R&D and its applications. There are many difficult questions that must be addressed, including considerations of the educational system, the potential displacement of skilled and unskilled laborers alike, the impacts of increased life expectancy, and the general changes in the delivery of all manner of goods and services. Government and business alike have a responsibility to take the longer view, to assess the impacts of technological change, and to develop alternative postures that can assure that the benefits of technological change can be realized without serious disruption to the society.

*GOGOs include, for example, the major facilities of the Department of Defense and NASA (except the Jet Propulsion Laboratory). GOCOs include, for example, the major Department of Energy establishments, such as the Pacific Northwest Laboratories (managed by Battelle), and the Argonne and Brookhaven National Laboratories.

Estimation of Sectoral R&D Activities, 1986

As noted in an earlier section of this forecast, the distribution of industrial R&D according to the broad categories (as seen in Table 4) is fraught with the potentials for misunderstanding. The classifications of enterprises in terms of their principal lines of business totally neglects the fact that many diverse companies conduct research in many diverse areas: "oil" companies do research in chemicals; "chemical" companies conduct programs in electronic materials; "electronics" companies do research on glass; and "glass" companies are involved in studies of construction technology.

Although Battelle has initiated programs which address the question of line-of-business R&D within selected broad industries, there are no reliable compilations of data which provide details on the levels of R&D in, for example, chemicals, rubber and plastics, electronic materials, or machinery. However, an indirect approach has evolved from other Battelle work and an initial estimate of R&D distribution can now be forwarded.

After several years' work on the inclusion of R&D activity in Battelle's Input-Output (I/O) model of the United States economy, it has become possible to use this material as an alternative basis of R&D forecasts, and as a source of increased industry detail in ascribed R&D.* Therefore, we are including a brief description of this method in the 1986 Forecast & Analysis, along with an indication of the new information it provides. Work will continue on this approach in the hope that it can provide a major expansion in future annual forecasts.

Underlying Assumptions and Concepts

This approach to the projection and analysis of R&D activity includes several underlying assumptions and/or conceptions:

- R&D is sufficiently homogeneous across fields of applications to be treated as an I/O *sector*—that is, as an activity which "sells" its outputs to other product- or process-related activities.
- Regardless of whether purchased extramurally or performed intramurally, R&D can be treated as a productive input into the sector which performs it, purchases it, or benefits from it in special ways.
- The average cost-structure of R&D activity across the whole economy can be ascertained and will be reasonably relevant to any R&D-using (or R&D-procuring) sector.

On the foundation provided by these sets of assumptions, two R&D sectors were incorporated into an expanded 150-order version of the Battelle I/O model for use in a special application (the so-called "Cost of Fracture" report).* The "fracture model" was established to describe technically an economy comparable to that of the United States in 1978. The present, modified 130-order model is general, not fracture-specific, and is intended to describe an economy technically comparable to the United States in 1985.

Sources of Data

In the form used herein, there are three crucial data inputs into the model: (a) the ratio of R&D to sales in each sector; (b) the structure of the total domestic economic activity (expressed in terms of sectoral Total Domestic Outputs (TDOs); and (c) estimated or forecasted Gross National Product (GNP) for the target year. The sources used in the present model applications were those originally used for the "fracture study" as modified and/or updated into its current, more generalized form.

The R&D/Sales ratio. These data were originally established in the form of technical coefficients of the fracture model and were generated from the expert knowledge and/or opinion of selected industry specialists. In modifying them to their present form, they have been adjusted and updated by reference to two sets of company and industry R&D/sales ratios: those of the *Business Week* Industrial Scoreboard, based upon 819 corporate forms 10-K, as reported to the SEC**; and those of Schonfeld & Associates, based on over 5300 corporate forms 10-K***. These latter raw data have been classified and analyzed in a way different from that used by *Business Week*.

On the basis of these two sets of data, the R&D coefficients were re-formatted, modified and updated. However, it must be kept firmly in mind that both the

*We cannot, in this space, provide detailed information on Input-Output modeling. Those who are not generally familiar with this approach to economic forecasting and analysis may request a copy of the Battelle monograph, *A Businessman's Introduction to Input-Output*, by W. Halder Fisher and P. Israilevich (Economics and Policy Analysis Occasional Paper No. 45, February, 1984).

*J. J. Duga, et al., *The Economic Effects of Fracture in the United States*. U.S. Department of Commerce, National Bureau of Standards, Special Publication 647-2 (March, 1983).

**See *Business Week* Industrial Scoreboard, March 22, 1985, pp. 164-194.

***Schonfeld & Associates, *R&D Forecasts*, Seventh Edition, June, 1983.

original set of values and their present modifications involve judgmental, as well as statistical, determinations.

The Structure of TDO. The total outputs of the industrial sectors of any I/O model, when summed across the entire economy, involve a certain amount of multiple counting. The exact degree of multiple counting depends on the number of sectors into which the economy is divided, on the technologies of each sector, and on the sectoral (industrial) composition of economic activity. At this point, our interest is confined to the last of these three elements.

The industrial structure of the economy, as used herein, is measured in terms of the sectoral ratios, Sector TDO/ TDO, which sum to unity. The only currently available source from which these structural data can be derived are the values of Total Domestic Output reported in the 1978 fracture model.

Dollar Levels of Economic Activity. The best single-counted measurement of annual economic activity is provided by the Gross National Product (GNP), officially reported by the Department of Commerce in its *National Income and Product Accounts* (NIPA). The latest year for which a "solid" official estimate of GNP is available is 1984. Thus, the 1986 value was estimated by Battelle to be $4,399 billion.*

In order to obtain a multiple-counted summation of TDO for 1986, the estimated GNP has been multiplied by the ratio [Sum]TDO/GNP = 1.6, which characterizes all 1978 and later Battelle I/O tables at this general level of detail.

Some Preliminary Findings

The above-described procedure has generated preliminary estimates of total sales activity, R&D performance/ascriptions, and ratios of R&D to total sales for each of 130 industrial sectors, and for unascribed R&D in final demand. This provides a much more detailed distribution of R&D activity and/or benefits than

*This value has been interpolated between 1985 and 1990 estimates made by Battelle, as reported in *FIVE BASICS DESCRIPTOR ESSAYS: Selected Economic, Technological, and Political Trends Analyses to 1995*, by W. Halder Fisher and Stephen D. Millett, (Economics and Policy Analysis Occasional Paper No. 50, May, 1985).

TABLE 7. DISTRIBUTION OF BUSINESS SALES AND R&D ACTIVITY ACROSS BROAD CATEGORIES OF THE ECONOMY, UNITED STATES, 1985

Industrial Grouping	Total Sales	Total R&D	Percent of Business Total		R&D as a Percent of Sales
	Millions of Dollars		Sales	R&D	
Agriculture, Forestry, Fisheries	218,900	3,500	3.11	3.72	1.63
Mining & Quarrying	213,800	5,000	3.03	5.26	2.36
Food, Tobacco, & Textiles	625,000	5,600	8.88	5.83	0.89
Lumber & Wood Products	262,900	5,700	3.73	5.92	2.16
Chemicals & Rubber	533,000	11,900	7.57	12.44	2.24
Stone, Clay & Glass Products	97,200	1,400	1.38	1.49	1.48
Primary Metals	195,000	2,100	2.77	2.25	1.11
Fabricated Metal Products	155,200	2,200	2.20	2.30	1.42
Heavy Industry	67,200	1,700	0.95	1.82	2.60
Industrial Machinery & Equipment	119,900	4,400	1.70	4.64	3.72
Transportation Equipment	347,400	9,700	4.93	10.16	2.81
Electrical Machinery & Equipment	96,600	3,800	1.37	3.96	3.94
Special Electrical & Electronic Equipment	130,800	6,700	1.85	7.01	5.15
Scientific & Professional Instruments	40,800	2,500	0.58	2.60	6.13
Miscellaneous Manufacturing	61,900	1,400	0.88	1.52	2.36
Transportation Services	214,800	900	3.05	0.94	0.42
Public Utilities	381,200	2,500	5.41	2.64	0.66
Construction	650,000	5,100	9.23	5.36	0.79
Trade, Finance & Services	1,902,200	13,800	27.02	14.40	0.72
Miscellaneous and Repair Services	723,000	5,400	10.27	5.62	0.74
Total Business*	7,037,900	96,100	100	100	1.36

*Due to rounding, details will not add to totals.
Source: Battelle estimates (see text)

that previously available from NSF, McGraw-Hill, or even earlier Battelle forecasts. Since the I/O sectors used in this model are defined in terms of pure processes, rather than company or establishment SIC classifications, these R&D details are mainly in line-of-business terms.

The total preliminary estimate of 1986 R&D, as calculated from this approach is $115.88 billion, almost equal to that derived by an entirely different approach and cited earlier in this Forecast.

Broad Category Distribution of R&D

Although the Battelle I/O model is disaggregated into 130 sectors (with this number being variable depending upon the specific programs to which the model is applied), these sectors can be conveniently grouped into 20 broad categories. Many of these categories are similar to the broad industrial groupings utilized by NSF and McGraw-Hill in their reportings of R&D activity. However, it must also be emphasized that these groups of lines of business do not necessarily embrace the same business activities as do their SIC counterparts which bear the same or similar titles.

Table 7 shows the distribution of business-related R&D activity over these 20 broad categories, while Tables 8, 9 and 10 list the 10 largest sectors ranked, respectively, in terms of total sales, total R&D expenditures, and R&D as a percent of sales. Similar tables including all 130 sectors can be made available upon request.

TABLE 8. R&D ACTIVITIES OF TEN LARGEST INDUSTRIAL SECTORS AT 137-ORDER DETAIL. UNITED STATES, 1986.

Rank	Sector Title	Total Sales (Millions)	Total R&D (Millions)	R&D as a Percent of Sales
1	Trade	752,300	3,310	0.44
2	Real Estate	567,100	210	0.03
3	Food production	378,400	3,780	1.00
4	Constr.-residential	257,900	1,540	0.60
5	Motor vehicles	242,900	5,860	2.41
6	Finance & insurance	236,700	1,180	0.49
7	Petroleum refining	236,100	1,410	0.60
8	Constr.-nonresidential	228,600	1,370	0.60
9	Educational services	223,600	1,340	0.60
10	Other Bus./Prof. Srvcs.	161,800	4,040	2.50

TABLE 9. TEN LARGEST INDUSTRIAL SECTORS AT 137-ORDER DETAIL, IN TERMS OF R&D ACTIVITY. UNITED STATES, 1986.

Rank	Sector Title	Total Sales (Millions)	Total R&D (Millions)	R&D as a Percent of Sales
1	Motor vehicles	242,900	5,860	2.41
2	R&D	94,700	4,560	4.81
3	Other Bus./Prof. Srvcs.	161,800	4,040	2.50
4	Comps. & Off. Equipmt.	40,700	3,820	9.36
5	Pulp & Paper	127,400	3,800	2.98
6	Food production	378,400	3,780	1.00
7	Aircraft & Missiles	65,900	3,360	5.10
8	Trade	752,300	3,310	0.44
9	Ind. Organic Chem.	61,800	2,780	4.50
10	Radio, TV, commnctns.	45,500	2,270	5.00

TABLE 10. TEN LARGEST INDUSTRIAL SECTORS AT 137-ORDER DETAIL, IN TERMS OF R&D AS A PERCENT OF SALES. UNITED STATES, 1986.

Rank	Sector Title	Total Sales (Millions)	Total R&D (Millions)	R&D as a Percent of Sales
1	Comps. & Off. Equipmt.	40,787	3,821	9.36
2	Med., etc., instrmnts.	5,468	437	8.00
3	Drugs	24,373	1,949	8.00
4	Electronic compnts.	10,726	858	8.00
5	Photo equip., etc.	8,882	579	6.52
6	Toilet Preps.	9,663	579	6.00
7	Coal (underground)	18,546	1,112	6.00
8	Optical insts., etc.	3,476	208	6.00
9	Coal (surface & other)	29,490	1,769	6.00
10	Scientific instrmnts.	20,467	1,228	6.00

The approach employed in this estimate provides more detail relative to R&D expenditures within much narrower categories than had been previously available. While the results are subject to a compounding of errors which are inherent in the estimation techniques, the approach offers a means whereby diversified companies can begin to compare their total research efforts in comparable terms. Furthermore, it is important to note that the use of the *technology-based* I/O model, and the inclusion of a separate R&D sector, permits an assessment of the impacts of various technology-driven "what-if" questions.

Finally, in this section we note that the method addresses the *total* R&D conducted in the United States,

not just that which is performed by industry (as in Table 4). Government-funded programs in, for example, chemicals is ascribed to the sector which accounts for the technology of chemicals production, rather than to the industry or company which conducts the research or markets the final product.

TECHNICAL APPENDIX

NSF DEFINITIONS OF RESEARCH AND DEVELOPMENT

Many activities, from one viewpoint or another, may be termed "Research and Development". The National Science Foundation (NSF) has, since its inception, been concerned with both the definition and the measurement of R&D. We probably can do no better than again quote the most recent definitions that the NSF has evolved. By these definitions, we can say:

"*Research and development* . . . consist of basic and applied research in the sciences (including medical sciences) and in engineering and activities in development . . .

"*Research*, which encompasses both basic and applied, is systematic, intensive study directed toward fuller scientific knowledge of the subject studied.

"*Basic research*. For three of the sectors—federal government, universities and colleges, and other nonprofit institutions—the definition of basic research stresses that it is directed toward increases of knowledge in science with . . . a fuller knowledge of understanding of the subject under study, rather than a practical application thereof. To take account of an individual industrial company's commercial goals, the definition for the industry sector is modified to indicate that basic research projects represent . . . original investigations for the advancement of scientific knowledge . . . which do not have specific commercial objectives, although they may be in fields of present or potential interest to the reporting company.

"*Applied Research*. The following is the core definition in the NSF questionnaire sent to the universities and colleges: '*Applied research* is directed toward practical application of knowledge'. Here again, the definition for the industry survey takes account of the characteristics of industrial organizations it covers '. . . research projects which represent investigations directed to discovery of new scientific knowledge and which have specific commercial objectives with respect to either products or processes'. By this definition, applied research in industry differs from basic research chiefly in terms of objectives of the reporting company.

"*Development*. The NSF survey concept of development may be summarized as '. . . the systematic use of scientific knowledge directed toward the production of useful materials, devices, systems or methods, including design and development of prototypes and processes'."*

*National Science Foundation, *National Patterns of R&D Resources*. 1953-78/79. NSF 78-313, p. 25.

ABOUT BATTELLE

Battelle Memorial Institute is a science-based organization committed to the generation, application, and commercialization of technology. Wholly independent and with a wide range of technical capabilities, it supplies an added dimension to the research and planning activities of literally thousands of companies and government agencies each year.

Battelle's services range from research—conceptual, problem-solving, and product and process development—to on-site technical assistance to clients, to management of very large programs with a high technical content. Its major thrust areas are the life sciences, including biotechnology; manufacturing technology; advanced materials; electronics; information sciences; and engineered systems.

The Institute, with a staff of more than 7,500 scientists, engineers, and supporting specialists, has major research centers in the United States and Europe, as well as offices and representatives in many parts of the world. All of its expertise and facilities are managed on a highly integrated basis and are available to each of its clients. Resources from several locations can and are used synergistically to meet client needs in a variety of business arrangements.

Battelle's Columbus Division is the original research center of Battelle Memorial Institute. The Institute was founded by the Will of Gordon Battelle as a memorial to the Battelle family.

Its members were among the first settlers of Ohio and were prominent in the development of the state's steel industry. Since Battelle began operations in 1929, it has been guided by the fundamental concept that human welfare can—and should—be improved by science and technology.

Battelle
Columbus Division
505 King Avenue
Columbus, Ohio 43201-2693
Telephone (614) 424-6424

The corporate mark and name as it appears above is
a registered service mark or trademark of Battelle Memorial Institute.

81253.5 Printed in U.S.A.